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(58) Field of Search

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(54) Progressive image transmission using discrete wavelet transforms

(57) A method is disclosed of storing and progressively transferring a still image so that it can be conveniently previewed during the transfer and so that a user can terminate the transfer at an early stage if the image turns out to be undesirable. The method includes transforming the image into a plurality of decomposition levels 12, 14 using a discrete wavelet transform. Each decomposition level comprises a plurality of subimages, LL1, LH1, HL1, HH1, which allow reconstruction of an image representation of the still image. The decomposition levels are transmitted beginning with a base decomposition level providing a low level of image resolution and then proceeding with decomposition levels providing increasingly higher levels of image resolution. Within each decomposition level, rows of the various subimages are arranged or interlaced together in contiguous blocks, so that all data for a single row, at a single decomposition level, is transmitted together. At the receiving end of the transfer, the row blocks are reconstructed and displayed as they are received. The invention enables the initial display of a low resolution image which is gradually updated and sharpened, on a row-by-row basis, until a desired high resolution is achieved. The user may terminate the transfer at any point.

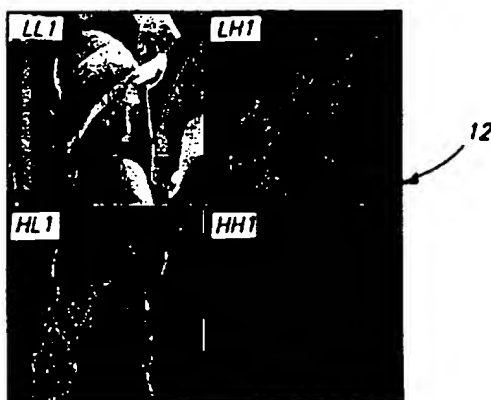


FIG. 2

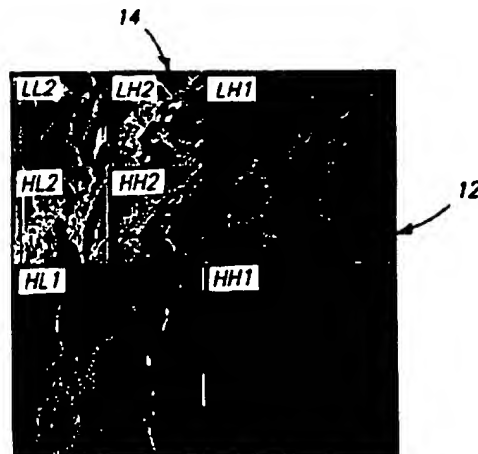


FIG. 3

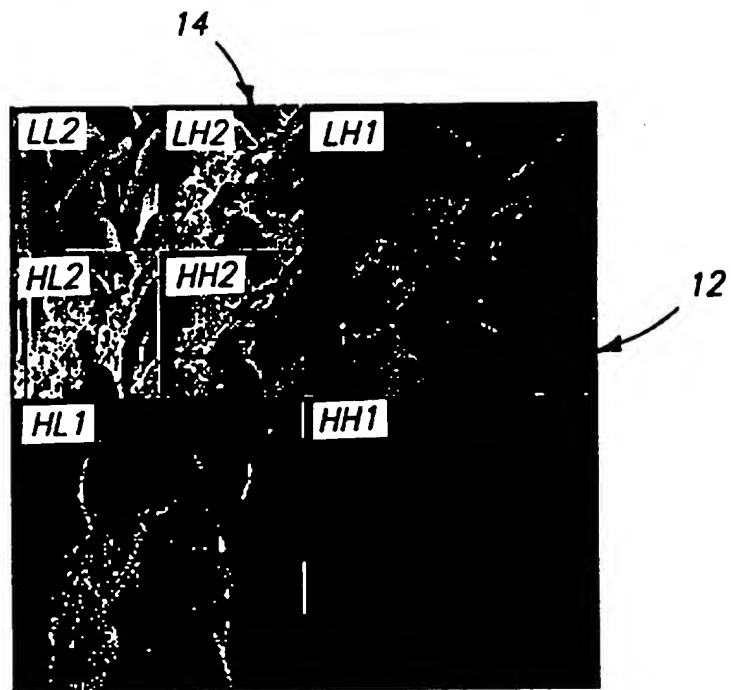
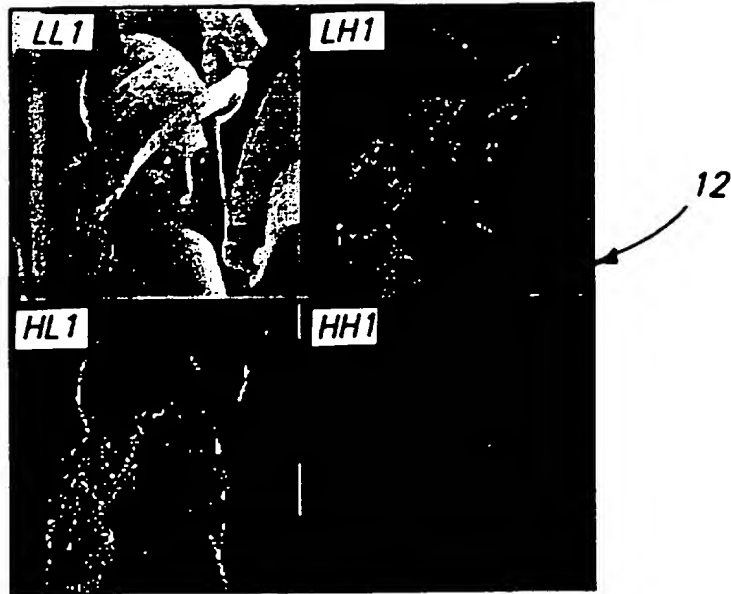
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FIG. 1



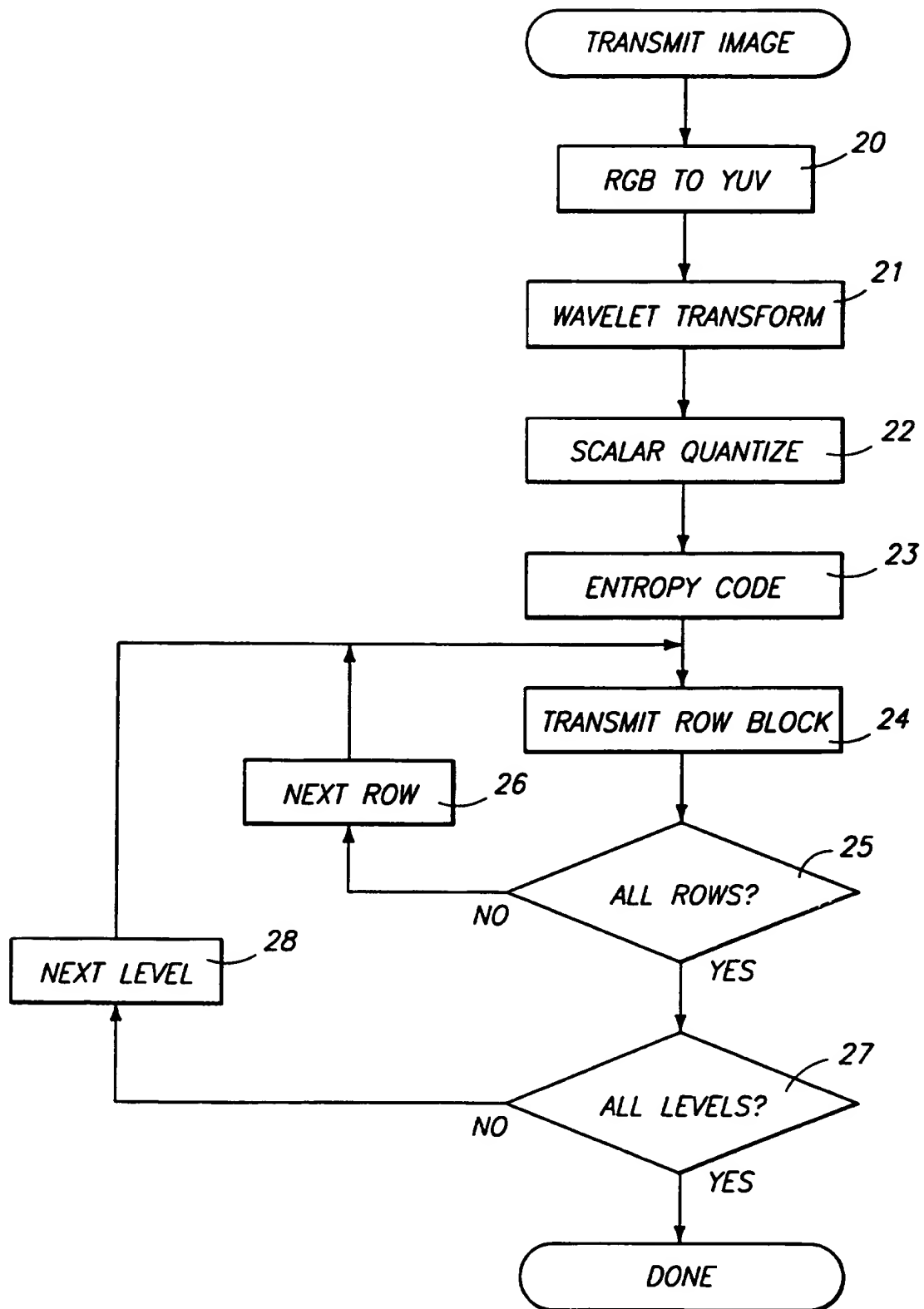


FIG. 4

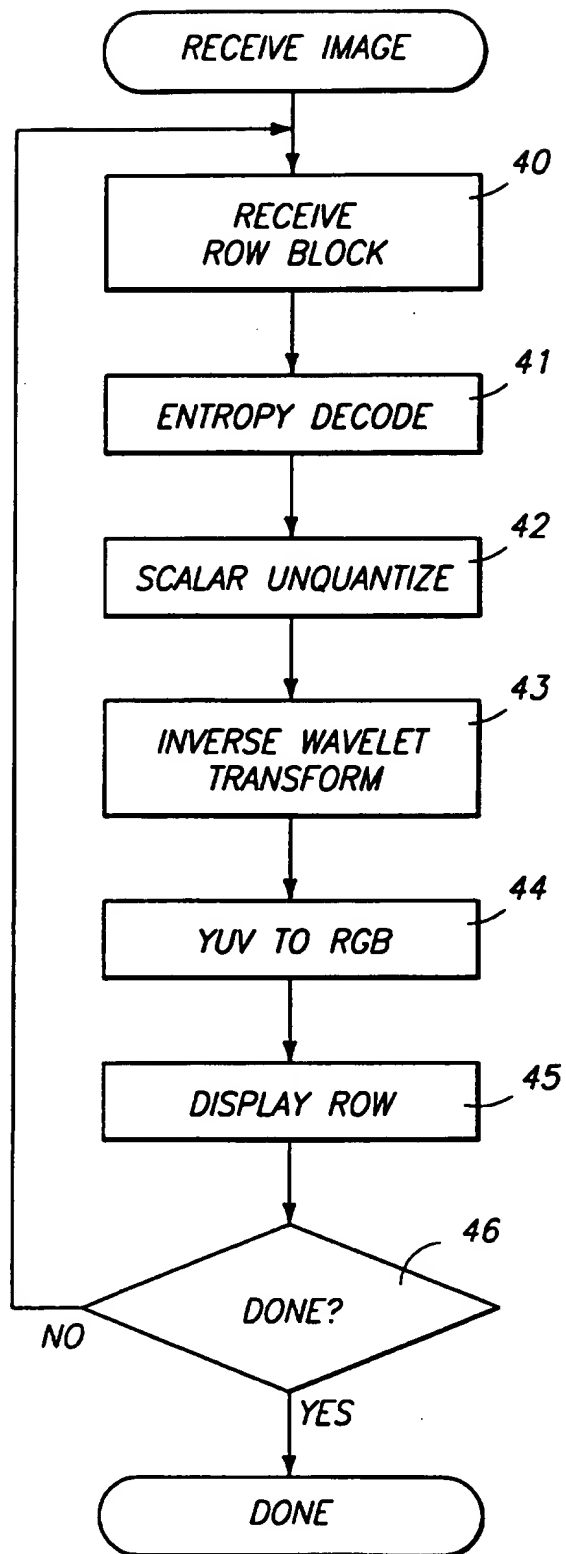


FIG. 5

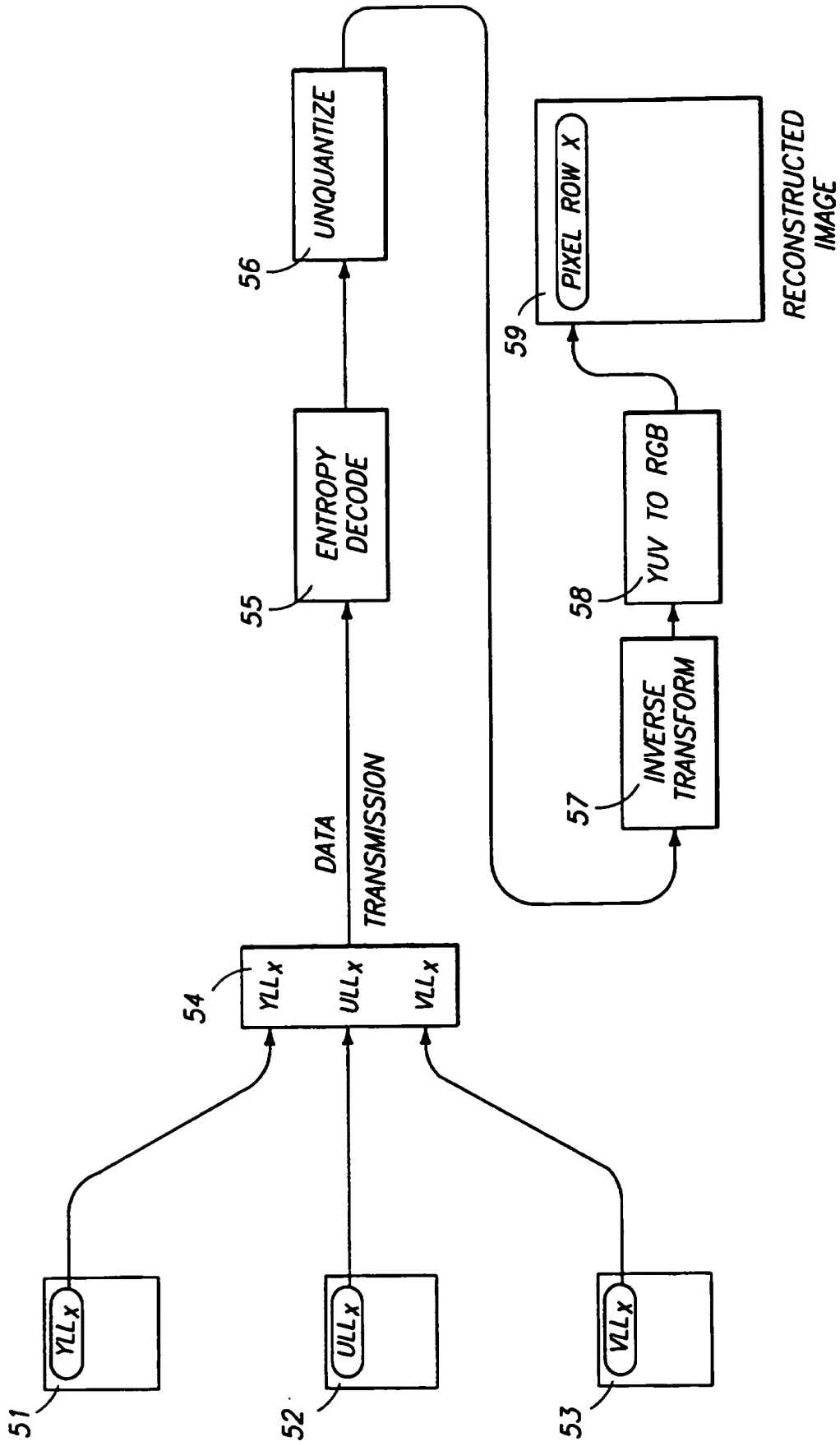


FIG. 6

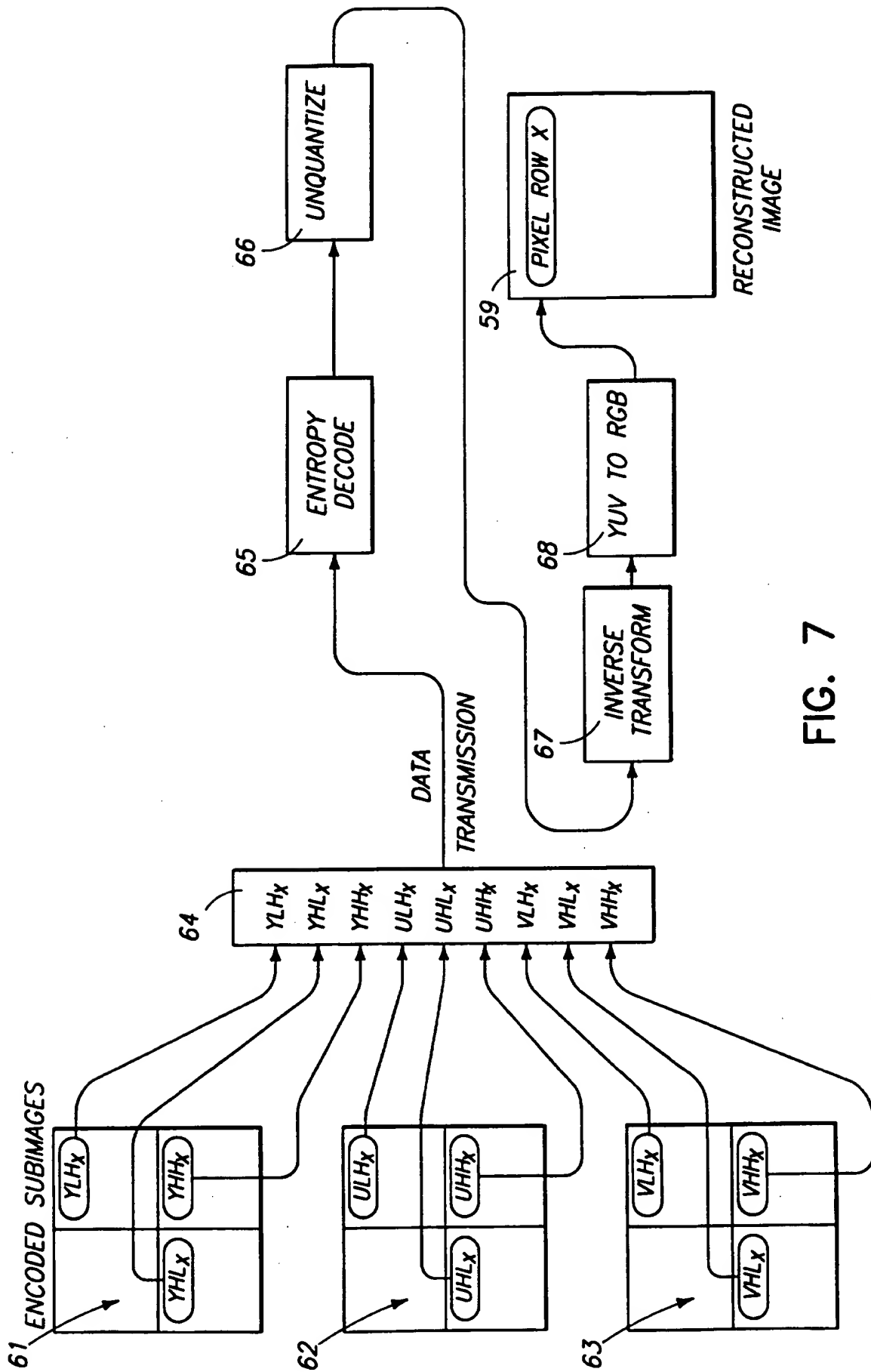


FIG. 7

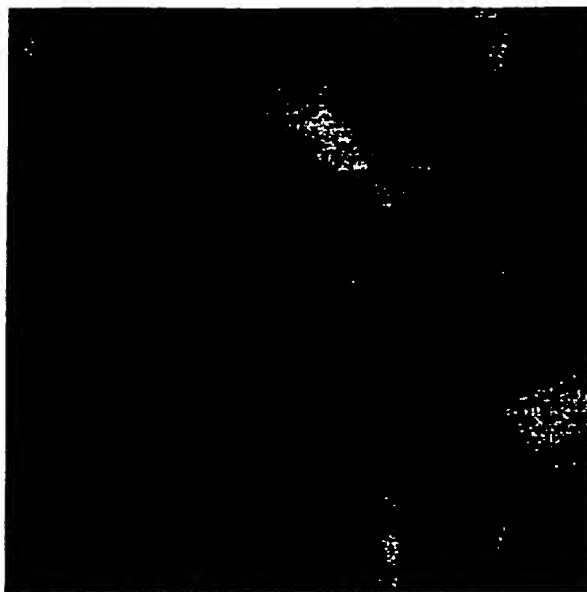


FIG. 8



FIG. 9



FIG. 10



FIG. 11

9110



FIG. 12

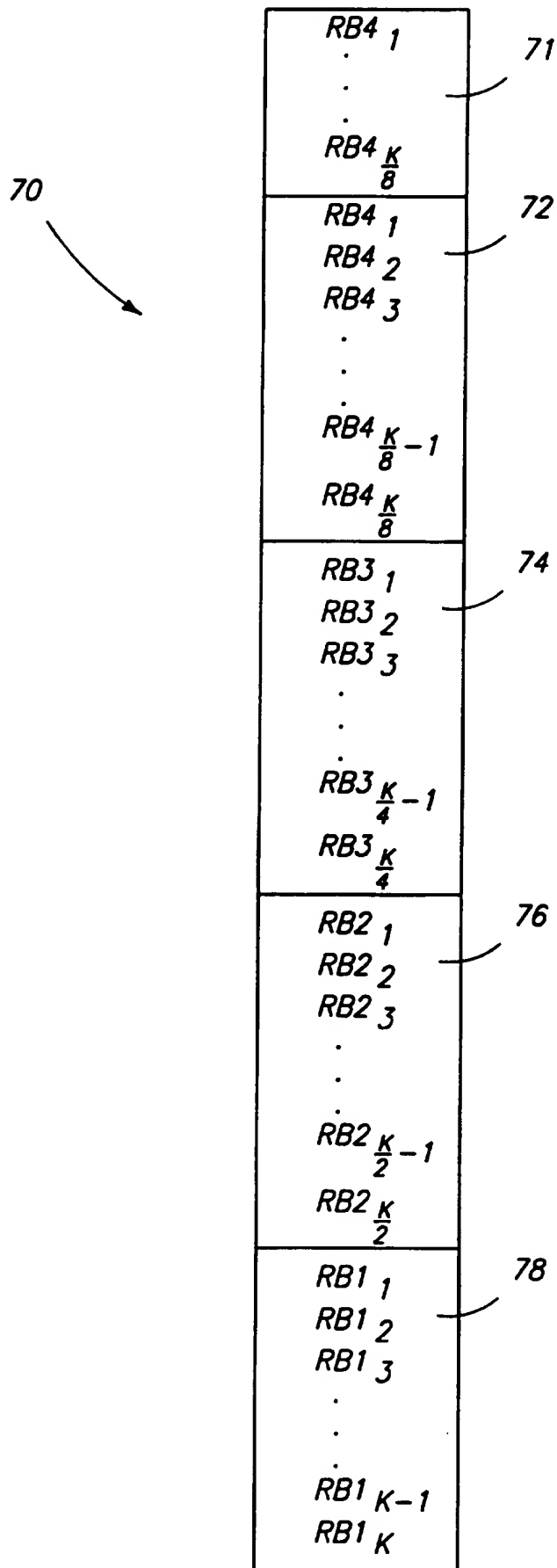


FIG. 13

1 TECHNICAL FIELD

2 This invention relates to methods and data structures for
3 transferring still images over relatively low-speed communication channels
4 to allow row-by-row viewing of the images at increasing levels of
5 resolution during image transfer.

6
7 BACKGROUND OF THE INVENTION

8 Digitally-formatted still graphic images are popular items among
9 users of public on-line information services. These services allow users
10 to select from large numbers of digitized images, and to download the
11 selected images for viewing on the user's own computer. The
12 availability and widespread use of high-resolution computer displays has
13 increased the demand for high-quality digitized images.

14 Despite the widespread availability of digitized images for
15 downloading, finding and obtaining useful images can be a frustrating
16 experience. This is due primarily to the large amount of data required
17 to represent a high-resolution computer image and to the corresponding
18 length of time required to download such an image to an individual's
19 personal computer using conventional telecommunication techniques.
20 Although data compression is commonplace, high-resolution images can
21 still take several minutes to transfer.

22 For instance, a true-color 640 by 480 pixel image, represented by
23 24 data bits per image pixel, takes at least 12 minutes to transfer using
24 a 9600 baud modem. Common data compression techniques can reduce

1 this time to perhaps one to two minutes. Even this delay, however,
2 can be very frustrating. Compounding the frustration is the very likely
3 possibility that the image, once it is transferred and viewed, will turn
4 out to be something quite different than what the user expected or
5 desired. Downloading and screening a number of images can easily
6 take hours.

7 Progressive image transmission is a technique used to reduce this
8 frustration to some degree. It allows a receiving computer to quickly
9 display a very low-resolution representation of the image being
10 downloaded. As more and more data is obtained by the user's
11 computer, the image is displayed at ever-increasing levels of resolution.
12 The user can terminate the transfer at any point if the image appears
13 to be unusable.

14 Discrete wavelet transformation is a recently developed technique
15 which has been used to compress still image data and to also facilitate
16 progressive image transmission. Several authors have described methods
17 for compressing and transmitting still image data using discrete wavelet
18 transformation. See, for example, the following articles, which are
19 hereby incorporated by reference:

- 20 A. Mallat, Stephane G., "A Theory for Multiresolution Signal
21 Decomposition: The Wavelet Representation", *IEEE Transactions*
22 *on Pattern Analysis and Machine Intelligence*, Vol. 11, No. 7, pp.
23 674-692 (July 1989)
24 B. Zettler, William R., et al., "Application of Compactly Supported
Wavelets to Image Compression", *Awave Technical Report AD900119*,
pp. 1-9 (1991)

- 1 C. Antonini, Marc, et al., "Image Coding Using Wavelet Transform",
2 *IEEE Transactions On Image Processing*, Vol. 1, No. 2, pp. 205-220
(April 1992)
- 3 D. Shapiro, Jerome M., "An Embedded Hierarchical Image Coder
4 Using Zerotrees Of Wavelet Coefficients", *IEEE Proceedings of Data
Compression Conference*, pp. 214-223 (1993)
- 5 E. Blanford, Ronald P., "Wavelet Encoding and Variable Resolution
6 Progressive Transmission", *NASA Space and Earth Science Data
Compression Workshop*, pp. 25-35 (1993)

7 In addition to the articles cited above, the following articles, also
8 incorporated by reference, give more general descriptions of discrete
9 wavelet transforms:

- 10 A. Baaziz, Nadia, et al., "Laplacian Pyramid Versus Wavelet
11 Decomposition for Image Sequence Coding", *IEEE International
Conference On Acoustics, Speech and Signal Processing*, pp. 1965-
12 1968, (1990)
- 13 B. Vetterli, Martin, et al., "Wavelets and Filter Banks: Relationships
14 and New Results", *IEEE International Conference on Acoustics,
Speech and Signal Processing*, pp. 1723-1726, (1990)
- 15 C. Press, William H., "Wavelet Transforms: A Primer", *Center for
Astrophysics*, Preprint Series No. 3184, pp. 1-24
- 16 D. Cody, Mac A., "The Fast Wavelet Transform--Beyond Fourier
17 Transforms", *Dr. Dobb's Journal*, pp. 16-28; 100-101, (April 1992)
- 18 E. Rioul, Olivier, et al., "Wavelets and Signal Processing", *IEEE
Signal Processing Magazine*, pp. 14-38, (October 1991)
- 19 F. Mallat, Stephane G., "A Compact Multiresolution Representation:
20 The Wavelet Model", *IEEE Proceedings of Workshop on Computer
Vision*, pp. 2-7, (1987)
- 21 G. Mallat, S.G., "Multiresolution Approach To Wavelets In Computer
22 Vision", *Proceedings of the International Conference*, Marseille,
23 France, pp. 313-327 (December, 1987)
- 24

1 H. Daubechies, Ingrid; Vetterling, William T.; Teukolsky, Saul A.;
2 Society for Industrial and Applied Mathematics, "The What, Why,
3 and How of Wavelets", *Ten Lectures on Wavelets*, Chapter 1,
4 pp. 1-16 (1992)

5 As explained by Zettler et al. at pages 2-4 of their article
6 entitled "Application of Compactly Supported Wavelets to Image
7 Compression," the term *wavelet* refers to an orthonormal basis for $L^2(\mathbb{R})$,
8 the square-integrable function on the real line, which is defined
9 recursively from a set of scaling function coefficients

$$\{a_k: k \in \{0, \dots, 2N - 1\}, N \in \mathbb{Z}^+, a_k \in \mathbb{R}\}$$

10
11 that satisfies the following conditions

$$\sum a_k = 2$$

$$\sum a_k^2 = 2$$

12
13
14
15
16 and more generally,

$$\sum a_k a_{k+2l} = 2\delta_{0l}$$

17
18
19 As further explained by Zettler et al., there are infinitely many
20 sets a_k for $N \geq 2$ that satisfy these conditions. These coefficients
21 implicitly define a scaling function $\phi(x)$ satisfying the following recursion:

$$\phi(x) = \sum a_k \phi(2x - k) \quad k \in \{0, \dots, 2N - 1\}$$

1 The scaling functions, their translates, the associated fundamental wavelet
 2 function $\psi(x)$, and scaled translates of ψ form an orthonormal basis for
 3 $L^2(\mathbb{R})$. The wavelet function ψ is defined in terms of the scaling
 4 function as

$$\psi(x) = \sum (-1)^k a_{k+1} \phi(2x + k) \quad k \in \{-1, \dots, 2N - 2\}$$

7 In one dimension, the discrete wavelet transform produces, from
 8 an input sequence $X = \{x_i\}$, two output sequences (with
 9 $k \in \{0, \dots, 2N - 1\}$):

$$\Phi = \{\phi_i\} = (1/\sqrt{2}) \{ \sum a_k x_{2i+k} \}$$

$$\Psi = \{\psi_i\} = (1/\sqrt{2}) \{ \sum (-1)^k a_{2N-1-k} x_{2i+k} \}$$

15 Since the discrete wavelet transform is invertible, it provides perfect
 16 reconstruction. Several variations of wavelet transformations, using the
 17 general principles described above, have been described in the articles
 18 cited.

19 Image data compression using discrete wavelet transforms begins
 20 by decomposing or transforming an image into four subbands or
 21 subimages using the above equations. Each subimage is one fourth the
 22 size of the original image, and contains one fourth as many data points
 23 as the original image. The image decomposition involves first
 24 performing a one-dimensional wavelet convolution on each horizontal

1 pixel column of the original image, thereby dividing the image into two
2 subimages containing low frequency and high frequency information
3 respectively. The same or a similar convolution is then applied to each
4 vertical pixel row of each subimage, dividing each of the previously
5 obtained subimages into two further subimages which again correspond
6 to low and high frequency image information. The resulting four
7 subimages can be referred to as LL, LH, HL, and HH subimages. The
8 LL subimage is the one containing low frequency information from both
9 the vertical and horizontal wavelet convolutions. The LH subimage is
10 the one containing low frequency image information from the horizontal
11 wavelet convolution and high frequency image information from the
12 vertical wavelet convolution. The HL subimage is the one containing
13 high frequency information from the horizontal wavelet convolution and
14 low frequency image information from the vertical wavelet convolution.
15 The HH subimage is the one containing high frequency information from
16 both the vertical and horizontal wavelet convolutions.

17 The result of this process is graphically illustrated in Figs. 1
18 and 2. Fig. 1 shows an original, uncompressed still image 10. Fig. 2
19 shows a first decomposition level 12 of the same image. Decomposition
20 level 12 is the result of transforming the still image of Fig. 1 using
21 vertical and horizontal passes of a discrete wavelet transform as
22 described above. Decomposition level 12 includes four subimages which
23 are compositely grouped for purposes of illustration. The subbands or
24 subimages of this first decomposition level are designated as the LL1,

1 LH1, HL1, and HH1 subimages, in accordance with the nomenclature
2 already given, with the suffix 1 indicating the first decomposition level.
3 The LL1 subimage contains the low frequency information from the
4 original image. Note that subimage LL1, when represented on a screen
5 display, appears like the original image except at a lower resolution or
6 size. The LH1 subimage contains high frequency information occurring
7 in a vertical direction. The HL1 subimage contains high frequency
8 information occurring in a horizontal direction. The HH1 subimage
9 contains high frequency information occurring in a diagonal direction.
10 In combination, the four subimages contain all the information necessary
11 to reconstruct the original image.

12 The first decomposition level can be further decomposed to
13 include a second decomposition level 14 as shown in Fig. 3. This
14 further decomposition is performed only on subimage LL1 of first
15 decomposition level 12. To decompose subimage LL1, horizontal and
16 vertical wavelet convolutions are performed on subimage LL1 in the
17 same manner as the same operations have already been performed on
18 the original image. This step subdivides subimage LL1 into LL2, LH2,
19 HL2, and HH2 subimages. Again, subimage LL2 looks like the original
20 image, except that it has a much lower resolution. Specifically, the LL
21 subimage at each decomposition level has one fourth as many data
22 points as the LL subimage of the next higher decomposition level.

23 The wavelet transforms described above are performed recursively
24 on each successively obtained LL subimage. For the practical purposes

1 to be accomplished by the invention described below, it has generally
2 been found that calculating four or five decomposition levels is
3 sufficient.

4 To reconstruct the original image, the inverse wavelet transform
5 is performed recursively at each decomposition level. Assuming a two-
6 level compression scheme, the second decomposition level contains a
7 subimage LL2 which is a low resolution or base representation of the
8 original still image. To obtain a higher resolution, subimage LL1 is
9 reconstructed by performing an inverse wavelet transform using the
10 subimages of the second decomposition level. The original image, at
11 the highest available resolution, can subsequently be obtained by
12 performing the inverse transform using the subimages of the first
13 decomposition level (but only after obtaining subimage LL1 through an
14 inverse transform of the second decomposition level).

15 The attractiveness of the wavelet approach to image transmission
16 is that subimages LH, HL, and HH contain data which can be
17 efficiently compressed to very high compression ratios through such
18 methods as run-length and Huffman encoding. The preferred
19 embodiments of the invention retain this advantage. In addition, the
20 invention provides efficient methods of storing and transmitting still
21 image data to allow the image to be quickly reconstructed and
22 displayed, at ever-increasing resolutions, for early user evaluation. If
23 the still image is found by the user to be unacceptable at any time
24

1 during transmission, the transmission and reconstruction can be aborted
2 before significant time is wasted.
3

4 SUMMARY OF THE INVENTION

5 The preferred embodiment of the invention includes a step of
6 transforming a still image so that it can be conveniently previewed
7 during transfer of the image over relatively low-speed data
8 communication links such as telephone lines. The methods of the
9 invention include transforming the image into a plurality of
10 decomposition levels using a hierarchical subband encoding scheme such
11 as the discrete wavelet transform. Each decomposition level comprises
12 a plurality of subimages which allow reconstruction of an image
13 representation of the still image. The decomposition levels are
14 transmitted beginning with a base decomposition level or image
15 representation, providing a low level of image resolution, and then
16 proceeding with decomposition levels providing increasingly higher levels
17 of image resolution. Each decomposition level can be inversely
18 transformed to yield an image representation at a higher level of
19 resolution. Within each decomposition level, rows of the various
20 subimages are arranged or interlaced together in contiguous blocks, so
21 that all data for a single row, at a single decomposition level, is
22 transmitted together. At the receiving end of the transfer, the row
23 blocks are reconstructed and displayed as they are received. The
24 preferred embodiment of the invention enables the initial display of a

1 low resolution image which is gradually updated and sharpened, on a
2 row-by-row basis, until a desired high resolution is achieved. The user
3 may terminate the transfer at any point if the image is not what is
4 desired.

5 6 BRIEF DESCRIPTION OF THE DRAWINGS

7 Figs. 1-3 show a still image at various levels of decomposition in
8 accordance with the methods of the invention.

9 Fig. 4 is a flow diagram showing preferred steps of transmitting
10 a still image in accordance with the invention.

11 Fig. 5 is a flow diagram showing preferred steps of receiving and
12 displaying a still image in accordance with the invention.

13 Figs. 6 and 7 are figurative representations of the preferred steps
14 of the invention.

15 Figs. 8-12 show an example of how the still image of Fig. 1
16 might appear as it is received and displayed at increasing levels of
17 resolution.

18 Fig. 13 shows a data file, in diagrammatic form, for storing a still
19 image in accordance with a preferred embodiment of the invention.

20 21 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

22 The invention described below is useful for storing, transferring,
23 receiving, and viewing still images. The invention is particularly useful
24 in combination with transferring images over serial transmission media

1 such as public voice-grade telephone lines or ISDN (integrated services
2 digital network) communication channels. The preferred embodiment is
3 described with reference to grey-scale or RGB still images. A grey-
4 scale image comprises a single color plane having a matrix of pixel or
5 intensity values corresponding to pixel intensities. An RGB image
6 comprises three discrete color planes which each contain a matrix of
7 pixel or intensity values corresponding to pixel intensities. An "R" color
8 plane contains intensities for the red components of pixels. A "G"
9 color plane contains intensities for the green components of pixels. A
10 "B" color plane contains intensities for the blue components of pixels.
11 Other still image representations could also be transferred using the
12 methods of the invention.

13 The preferred steps of transferring an original image are shown
14 in Fig. 4. A first step 20 comprises converting the color planes of the
15 RGB image to luminance and chrominance (YUV) planes using well-
16 known techniques. A subsequent step 21 comprises transforming the
17 converted original image into a plurality of decomposition levels using
18 a hierarchical subband encoding scheme such as the wavelet
19 transformation process described in the Background of the Invention
20 section. Each decomposition level comprises a plurality of subimages
21 which allow reconstruction of an image representation of the original
22 still image. Transforming step 21 includes calculating a separate set of
23 subbands or subimages in each decomposition level for each luminance
24 and chrominance plane. In other words, each YUV plane is

1 transformed separately, and each decomposition level comprises a
2 plurality or set of subimages for each YUV plane. Although the
3 various steps are given with reference to a color YUV image, the
4 methods work equally well with greyscale images which include only a
5 single color, intensity, or luminance plane.

6 Step 21 preferably comprises creating at least three, and
7 preferably four or more decomposition levels. Assuming four
8 decomposition levels for purposes of explanation, the fourth
9 decomposition level is considered a low resolution "base" decomposition
10 level. It includes subimages YLL4, YLH4, YHL4, and YHH4 for the
11 Y plane; ULL4, ULH4, UHL4, and UHH4 for the U plane, and VLL4,
12 VLH4, VHL4, and VHH4 for the V plane.

13 The fourth decomposition level is nested within a third
14 decomposition level having a relatively higher resolution. The third
15 decomposition level contains, in addition to the fourth decomposition
16 level, subimages YLH3, YHL3, YHH3, ULH3, UHL3, UHH3, VLH3,
17 VHL3, and VHH3. Note that the base decomposition level is the only
18 one which contains an explicitly specified LL subimage. The LL
19 subimages of the higher resolution subimages are represented by the
20 lower or nested decomposition levels, and must be calculated or
21 inversely transformed from the lower or nested decomposition levels.
22 The second decomposition level, at an even higher resolution than the
23 third, contains the third decomposition level and subimages YLH2,
24 YHL2, YHH2, ULH2, UHL2, UHH2, VLH2, VHL2, and VHH2. The

1 first decomposition level contains the second decomposition level and
2 subimages YLH1, YHL1, YHH1, ULH1, UHL1, UHH1, VLH1, VHL1,
3 and VHH1.

4 Each subband or subimage contains rows of subimage values
5 corresponding to rows of the image representation provided by the
6 corresponding decomposition level. As already described, each subimage
7 at a given decomposition level contains information regarding different
8 frequency components of the original image or of the LL subimage of
9 the next higher decomposition level. The various decomposition levels
10 provide increasingly higher levels of image resolution.

11 Steps 22 and 23 of Fig. 4 comprise performing scalar quantization
12 and entropy coding, respectively. The transformed image is scalar
13 quantized on a level-by-level basis. The quantized values are also
14 preferably compressed or encoded using Huffman and run-length
15 encoding. Various forms of run-length encoding can be used for this
16 purpose, as well as the other forms of data compression proposed in
17 the cited literature.

18 The decomposition levels are successively transmitted, starting with
19 the base decomposition level, which provides only a low resolution, and
20 continuing with decomposition levels providing increasingly higher levels
21 of image resolution. The decomposition levels are transmitted in
22 accordance with steps 24 through 28 of Fig. 4. As indicated by step
23 24 the subimages are transmitted as contiguous row blocks. A
24 particular row block contains all the subimage values necessary to allow

1 reconstruction of a single row of an image representation at the
2 resolution of a particular decomposition level. This reconstructed row
3 forms one row of the LL subimage of the next higher decomposition
4 level.

5 For a greyscale image, a row block comprises a single pixel row
6 from each subimage of the selected decomposition level. For a color
7 YUV image, the row block comprises a single pixel row from each
8 subimage of each color plane of the selected decomposition level. For
9 instance, a row block might comprise a pixel row from each of
10 subimages YLH, YHL, YHH, ULH, UHL, UHH, VLH, VHL, and VHH
11 of the selected decomposition level.

12 Step 24 is repeated for successive row blocks of a single
13 decomposition level until all the rows of the subimages from the current
14 decomposition level have been selected and transmitted. This is
15 indicated by blocks 25 and 26 in Fig. 4. The process is then repeated
16 for subsequent decomposition levels as indicated by blocks 27 and 28.
17 This process continues until all row blocks of all decomposition levels
18 have been transmitted.

19 As a specific example, transmission begins with a fourth or base
20 decomposition level. Transmission of the base decomposition level
21 begins with only its LL subimages to allow immediate display of a very
22 rough image representation. For the color image being described
23 herein, this includes subimages YLL4, ULL4, and VLL4. Transmission
24 begins with a row block comprising the first row of YLL4, the first row

1 of ULL4, and the first row of VLL4. Transmission continues with a
2 subsequent row block comprising the second row of YLL4, then the
3 second row of ULL4, and then the second row of VLL4. The
4 remaining rows of subimages YLL4, ULL4, and VLL4 follow, arranged
5 in further row blocks.

6 Transmission of the remaining subimages of the fourth
7 decomposition level then continues, starting with a row block containing
8 the first row of each of subimages YLH4, YHL4, YHH4, ULH4, UHL4,
9 UHH4, VLH4, VHL4, and VHH4. The next row block contains the
10 second row of each of subimages YLH4, YHL4, YHH4, ULH4, UHL4,
11 UHH4, VLH4, VHL4, and VHH4. The remaining rows of subimages
12 YLH4, YHL4, YHH4, ULH4, UHL4, UHH4, VLH4, VHL4, and VHH4
13 are similarly arranged and transmitted in sequential row blocks.

14 Transmission then continues with the third decomposition level,
15 starting with a row block containing the first row of each of subimages
16 YLH3, YHL3, YHH3, ULH3, UHL3, UHH3, VLH3, VHL3, and VHH3.
17 Note that this decomposition level does not contain LL subimages, since
18 the LL subimages of the decomposition level can be reconstructed from
19 the already-transmitted fourth decomposition level. The next row block
20 contains the second row of each of subimages YLH3, YHL3, YHH3,
21 ULH3, UHL3, UHH3, VLH3, VHL3, and VHH3. The remaining rows
22 of subimages YLH3, YHL3, YHH3, ULH3, UHL3, UHH3, VLH3,
23 VHL3, and VHH3 are similarly arranged and transmitted in sequential
24 row blocks.

1 The second and then the first decomposition levels are transmitted
2 with the same ordering or interlacing of rows from the various
3 subimages.

4 Thus, in accordance with methods of Fig. 4, an image is
5 transmitted as a succession of decomposition levels allowing progressive
6 reconstruction of the original image at ever-increasing levels of spacial
7 resolution. Furthermore, information is transmitted on a line-by-line or
8 row-by-row basis. Within a given decomposition level, all information
9 for the first row, including the row information from all subimages and
10 from all color planes, is transmitted as a single row block. This allows
11 the image to be reconstructed line-by-line as it is received. A user is
12 thus allowed the opportunity to abort transmission at any time, after
13 viewing the image at a coarse resolution.

14 Fig. 5 illustrates the preferred steps of receiving and
15 reconstructing an image. Block 40 indicates a step of receiving the row
16 blocks discussed above. Steps 41 through 45 comprise reconstructing
17 successive pixel rows corresponding to the still image at increasing levels
18 of resolution by inversely transforming and displaying each row block.
19 These steps are performed on each row block as it is received. Step
20 41 comprises entropy decoding; step 42 comprises scalar unquantization;
21 step 43 comprises inverse wavelet transformation; and step 44 comprises
22 YUV to RGB conversion. These steps are performed on each row of
23 the current decomposition level and thereby reconstruct the
24 corresponding row or rows of the next-higher decomposition level. This

1 reconstruction creates a sequence of reconstructed images at increasing
2 sizes corresponding to increasing resolution levels.

3 Step 45 comprises displaying each successive pixel row of each
4 decomposition level as it is received and reconstructed. This allows a
5 user to evaluate an image *during its reception*, without having to wait for
6 the complete transfer of an image or even for the complete transfer of
7 a decomposition level. Step 45 preferably includes a step of expanding
8 each successive reconstructed image to a common size before actually
9 displaying it. Such expansion is preferably accomplished with bilinear
10 interpolation or pixel averaging in accordance with known techniques.
11 Displaying step 45 might also include appropriate dithering if the image
12 is to be displayed using a color palette which is smaller than that used
13 to create the original image.

14 The transmission and reconstruction of single row blocks is
15 figuratively shown in Figs. 6 and 7. Fig. 6 shows Y, U, and V LL
16 subimages 51, 52, and 53 of a base decomposition level, with a single
17 pixel row x being selected from each LL subimage. The selected pixel
18 rows are combined to form a row block 54. The single row block is
19 transmitted as a block. After such transmission, entropy decoding,
20 unquantizing, inverse transformation, and YUV to RGB conversion steps
21 55 through 58 are performed. This yields a single row x of a
22 reconstructed image 59. Sequential rows of the LL subimages are
23 blocked, transmitted, and reconstructed to yield all the pixel rows of
24 image 59 at the base decomposition level.

1 Fig. 7 shows Y, U, and V subimages 61, 62, and 63 of a
2 decomposition level which may or may not be a base decomposition
3 level. Transmission in this case does not include LL subimages. Again,
4 a single pixel row x is selected from each subimage. The selected pixel
5 rows are combined to form a single contiguous row block 64 which is
6 transmitted as a block. After such transmission, entropy decoding,
7 unquantizing, inverse transformation, and YUV to RGB conversion steps
8 65 through 68 are performed. This yields a single row x of
9 reconstructed image 59 at a higher resolution than previously available.
10 Sequential rows of the subimages are blocked, transmitted, and
11 reconstructed to yield all the pixel rows of image 59 at the resolution
12 of the current decomposition level. This process is repeated at each
13 decomposition level, so that image 59 is displayed at ever-increasing
14 levels of resolution.

15 The specific arrangement and timing of the image transmission
16 allows a user to view each portion of an image at the earliest possible
17 moment. The image will be first drawn at a base or low level of
18 resolution, corresponding to the LL subimages of the base decomposition
19 level, starting at the top row and proceeding downward. During
20 reception of the remaining subimages of the base decomposition level,
21 the display will be updated, again row-by-row. The user will perceive
22 a slight increase in sharpness, occurring gradually from top to bottom
23 of the image. Further sharpness will be provided during reception of
24 subsequent decomposition levels, until the image is fully reconstructed

1 at its original resolution. Transmission can be aborted at any time by
2 the user.

3 The result is illustrated by the sequence of displays shown in Figs.
4 8 through 12. An initial image representation appears at a very low
5 resolution as shown in Fig. 8. Note that this representation reflects the
6 use of bilinear interpolation. This greatly enhances the recognizability
7 of the image. The rough image of Fig. 8 is gradually updated, row by
8 row, bottom to top, as row blocks of the next higher decomposition
9 level are received and inversely transformed to achieve an image
10 representation such as shown by Fig. 9. Reception and inverse
11 transformation of further decomposition levels achieves the
12 representations of Figs. 10 and 11. Reception of the last decomposition
13 level results in the high-resolution image of Fig. 12. The visual effect
14 to a user is pleasing. Rather than seeing a succession of disjointed
15 images, at increasing unrelated sizes, the user sees a single image of
16 a fixed size, which gradually sharpens, row-by-row, to a very high
17 resolution.

18 When the receiving computer is relatively slow, reconstructing steps
19 41 through 45 of Fig. 5 can be implemented to reconstruct and display
20 only the luminance (Y) plane of the received YUV image. The
21 luminance plane appears as a greyscale representation of an original
22 color image and will in many cases be acceptable for previewing an
23 image. Further reconstruction of the chrominance (UV) planes can be
24

1 postponed until the user requests a full-color display of the original
2 image.

3 It is advantageous to actually store still images in the
4 decomposed, compressed, and ordered format described above. This
5 minimizes storage space and also minimizes the recurring processing
6 costs which would otherwise be necessary to transform and arrange the
7 image data prior to or during each transfer. The invention thus
8 includes a data file arranged as shown schematically in Fig. 13 for
9 storing a still image. The data file is generally designated by the
10 reference numeral 70. It comprises a plurality of decomposition levels
11 representing the original still image at increasingly higher levels of
12 resolution. The decomposition levels are arranged within the data file
13 in order of increasing levels of resolution (shown from top to bottom
14 in Fig. 13). For instance, the LL data from a fourth or base
15 decomposition level is stored first in a data block 71, followed by the
16 remaining LH, HL, and HH data of fourth decomposition level in a
17 data block 72. This is followed by a third decomposition level in a
18 data block 74, a second decomposition level in a data block 76, and
19 a first decomposition level in a data block 78.

20 As described above, each decomposition level comprises a plurality
21 of subimages which allow reconstruction of an image representation
22 corresponding to the original image. The subimages have rows of
23 subimage values corresponding to rows of the image representation.
24

1 The subimages are preferably transformed with a discrete wavelet
2 transform.

3 Each decomposition level comprises a separate set of subimages
4 for each luminance and chrominance plane of the still image. However,
5 the rows of the various subimages are arranged within the data file and
6 within each particular decomposition level to form row blocks as shown
7 in Fig. 13. Each row block in Fig. 13 is indicated by the designation
8 $RB\#_x$, where # indicates the decomposition level and the subscripted
9 value indicates a particular row of the subimages of the decomposition
10 level. As shown, the row blocks are arranged starting with a top
11 row 1 of the subimages and ending with the bottom row of the
12 subimages. The value K indicates the number of rows in the subimages
13 of the first decomposition level.

14 The rows in each block correspond to a single common row of
15 the image representation provided by the decomposition level containing
16 the row block. Each row block contains all the data required to
17 reconstruct said single row. Specifically, each row block contains a row
18 of data from each or at least a plurality of the subimages of the
19 decomposition level. For instance, a single row block contains $YLH\#_x$,
20 $YHL\#_x$, $YHH\#_x$, $ULH\#_x$, $UHL\#_x$, $UHH\#_x$, $VLH\#_x$, $VHL\#_x$, and
21 $VHH\#_x$, wherein x indicates a particular row of the subimages. The
22 row blocks are preferably compressed using a form of run-length
23 encoding and Huffman encoding.
24

1 The invention provides a needed improvement in the transfer of
2 still images over relatively low speed communication links. The ability
3 for a user to see enhancements to an initial, low-resolution image
4 representation, so that the displayed image representation gradually
5 sharpens to its full resolution on a line-by-line basis, is a particularly
6 pleasing and desirable advantage when previewing images. The
7 particular decomposition methods used provide additional advantages in
8 that they are computationally efficient and allow for efficient data
9 compression.

10 In compliance with the patent statute, the invention has been
11 described in language more or less specific as to structural and
12 methodical features. It is to be understood, however, that the invention
13 is not limited to the specific features shown and described, since the
14 means herein disclosed comprise preferred forms of putting the invention
15 into effect. The invention is, therefore, claimed in any of its forms or
16 modifications within the proper scope of the appended claims
17 appropriately interpreted in accordance with the doctrine of equivalents.
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1 CLAIMS:

2 1. A method of transferring a still image which is represented
3 by a plurality of decomposition levels, each decomposition level
4 comprising a plurality of subimages which allow reconstruction of an
5 image representation of the still image, said subimages having rows of
6 subimage values corresponding to rows of said image representation, the
7 decomposition levels providing increasingly higher levels of image
8 resolution, the method comprising the following steps:

9 successively transmitting the decomposition levels, starting with a
10 base decomposition level providing a low level of image resolution and
11 continuing with decomposition levels providing increasingly higher levels
12 of image resolution;

13 transmitting the subimage values of each particular decomposition
14 level as row blocks, wherein each row block contains a row of subimage
15 values from a plurality of subimages of the particular decomposition
16 level, and wherein the rows of each row block correspond to a common
17 image representation row.

18
19 2. A method as recited in claim 1 and further comprising:
20 receiving the row blocks of subimage values;
21 reconstructing successive pixel rows of the still image at increasing
22 levels of resolution as each row block is received;
23 displaying each reconstructed pixel row of the still image as it is
24 reconstructed.

1 3. A method as recited in claim 2 wherein the reconstructing
2 step comprises creating a sequence of reconstructed images at increasing
3 resolution levels.

4
5 4. A method as recited in claim 2 wherein:
6 the reconstructing step comprises creating a sequence of
7 reconstructed images at increasing sizes corresponding to increasing
8 resolution levels;

9 the method further comprises expanding the reconstructed images
10 to a common size before displaying them.

11
12 5. A method as recited in claim 2 wherein:
13 the reconstructing step comprises creating a sequence of
14 reconstructed images at increasing sizes corresponding to increasing
15 resolution levels;

16 the method further comprises interpolating to expand the
17 reconstructed images to a common size before displaying them.

18
19 6. A method as recited in claim 2 wherein the still image is
20 represented by luminance and chrominance planes, and wherein the
21 reconstructing and displaying steps reconstruct and display only the
22 luminance plane.

1 7. A method of transferring a still image, the method
2 comprising the following steps:

3 transforming the image into a plurality of decomposition levels,
4 wherein each decomposition level comprises a plurality of subimages
5 which allow reconstruction of an image representation of the still image,
6 said subimages having rows of subimage values corresponding to rows
7 of said image representation, the decomposition levels providing
8 increasingly higher levels of image resolution;

9 successively transmitting the decomposition levels, starting with a
10 base decomposition level providing a low level of image resolution and
11 continuing with decomposition levels providing increasingly higher levels
12 of image resolution;

13 transmitting the subimage values of each particular decomposition
14 level as row blocks, wherein each row block contains a row of subimage
15 values from a plurality of subimages of the particular decomposition
16 level, and wherein the rows of each row block correspond to a common
17 image representation row.

18
19 8. A method as recited in claim 7 wherein the transforming
20 step comprises calculating the plurality of decomposition levels using a
21 discrete wavelet transform.

22
23 9. A method as recited in claim 7 and further comprising
24 encoding the row blocks before transmitting them.

1 10. A method as recited in claim 7 and further comprising run-
2 length encoding the row blocks before transmitting them.

3
4 11. A method as recited in claim 7 wherein the still image
5 comprises chrominance and luminance planes and wherein the
6 transforming step comprises calculating a separate set of subimages in
7 each decomposition level for each luminance and chrominance plane.

8
9 12. A method as recited in claim 7 wherein the still image
10 comprises a plurality of color planes, the method further comprising
11 converting the color planes to chrominance and luminance planes before
12 the transforming step, wherein the transforming step comprises
13 calculating a separate set of subimages in each decomposition level for
14 each luminance and chrominance plane.

15
16 13. A method as recited in claim 7 and further comprising:
17 receiving the row blocks of subimage values;
18 reconstructing successive pixel rows of the still image at increasing
19 levels of resolution by inversely transforming each row block as it is
20 received;
21 displaying each reconstructed pixel row of the still image as it is
22 reconstructed.

23
24

1 14. A method as recited in claim 13 wherein the reconstructing
2 step comprises creating a sequence of reconstructed images at increasing
3 resolution levels.

4
5 15. A method as recited in claim 13 wherein:
6 the reconstructing step comprises creating a sequence of
7 reconstructed images at increasing sizes corresponding to increasing
8 resolution levels;

9 the method further comprises expanding the reconstructed images
10 to a common size before displaying them.

11
12 16. A method as recited in claim 13 wherein:
13 the reconstructing step comprises creating a sequence of
14 reconstructed images at increasing sizes corresponding to increasing
15 resolution levels;

16 the method further comprises interpolating to expand the
17 reconstructed images to a common size before displaying them.

18
19 17. A method as recited in claim 13 wherein the still image is
20 represented by luminance and chrominance planes, and wherein the
21 reconstructing and displaying steps reconstruct and display only the
22 luminance plane.

1 18. A method of transferring a still image, the method
2 comprising the following steps:

3 transforming the image into a plurality of decomposition levels
4 using a discrete wavelet transform, wherein each decomposition level
5 comprises a plurality of subimages which allow reconstruction of an
6 image representation of the still image, said subimages having rows of
7 subimage values corresponding to rows of said image representation, the
8 decomposition levels providing increasingly higher levels of image
9 resolution;

10 successively transmitting the decomposition levels, starting with a
11 base decomposition level providing a low level of image resolution and
12 continuing with decomposition levels providing increasingly higher levels
13 of image resolution;

14 transmitting the subimage values of each particular decomposition
15 level as row blocks, wherein each row block contains a row of subimage
16 values from a plurality of subimages of the particular decomposition
17 level, and wherein the rows of each row block correspond to a common
18 image representation row;

19 receiving the row blocks of subimage values;

20 reconstructing successive pixel rows of the still image at increasing
21 levels of resolution by inversely transforming each row block as it is
22 received;

23 displaying each reconstructed pixel row of the still image as it is
24 reconstructed.

1 19. A method as recited in claim 18 and further comprising
2 encoding the row blocks before transmitting them.

3
4 20. A method as recited in claim 18 and further comprising
5 run-length encoding the row blocks before transmitting them.

6
7 21. A method as recited in claim 18 wherein the still image
8 comprises chrominance and luminance planes and wherein the
9 transforming step comprises calculating a separate set of subimages in
10 each decomposition level for each luminance and chrominance plane.

11
12 22. A method as recited in claim 18 wherein the still image
13 comprises a plurality of color planes, the method further comprising
14 converting the color planes to chrominance and luminance planes before
15 the transforming step, wherein the transforming step comprises
16 calculating a separate set of subimages in each decomposition level for
17 each luminance and chrominance plane.

1 23. A data file for storing a still image, the data file
2 comprising:

3 a plurality of decomposition levels representing the still image at
4 increasingly higher levels of resolution, the decomposition levels being
5 arranged in order of increasing levels of resolution;

6 individual decomposition levels each comprising a plurality of
7 subimages which allow reconstruction of an image representation of the
8 still image, said subimages having rows of subimage values corresponding
9 to rows of said image representation;

10 said rows of subimage values being arranged within each particular
11 decomposition level in row blocks, each row block containing a row of
12 subimage values from a plurality of subimages of the particular
13 decomposition level, wherein the rows of each row block correspond to
14 a common image representation row.

15
16 24. A data file as recited in claim 23 wherein the subimages
17 are transformed with a discrete wavelet transform.

18
19 25. A data file as recited in claim 23 wherein the row blocks
20 are encoded.

21
22 26. A data file as recited in claim 23 wherein the row blocks
23 are run-length encoded.

1 27. A data file as recited in claim 23 wherein each
2 decomposition level comprises a separate set of subimages for each
3 luminance and chrominance plane of the still image.

32

Patents Act 1977
Examiner's report to the Comptroller under Section 17
(The Search report)

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 (ii) Int Cl (Ed.6) H04N 1/41, 7/26, 11/00

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 MR J P COULES

Date of completion of Search
 6 FEBRUARY 1996

Databases (see below)

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